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Electrical energy storage systems for increasing technical and economical characteristics of gas engine power plants

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Abstract. Developing of new technologies such as electrical energy storage systems (EESS) opens new ways to increasing efficiency, decreasing exhaust waste and fuel consumption in traditional fossil fuels power station. This paper contains actual testing results of electrical energy storage system based on lithium-ion technology working with gas engine generator and altering load power. EESS parameters: rated power 100 kVA, rated capacity 153 kWh. As is known, gas generators are sensitive to changes in load power, obtained results show the effectiveness of the usage EESS to supply sustainability of generators in high amplitude and frequency altering load power environment. These results achieved through the ability of the developed converter and control strategy to compensate rapid deviations of the load power. In additional, in control system realized others common functionality: active power limitation, voltage and frequency control, reactive power control, power factor control and others. With the usage EESS, the nominal power of plane station should be lower than without EESS.

1. Introduction

The global interest in reducing the volume of hydrocarbons burned caused a spread interest in the using of renewable generation (mainly solar power and wind power) at the electric power industries of most developed countries. However, this type of generation is not able to completely displace the traditional power stations because of its operation peculiarities, namely of the stochasticity of the generated power. This peculiarity allowed the development of a whole class of devices, which are now commonly referred to as electrical energy storage systems. Also, the development of electrical energy storage systems is due to the spread of electronic portable devices and electric transport, these industries have increased the specific capacity of batteries and reduce the cost of their production (the cost of batteries can be more than 50% in the cost of the electrical energy storage system).

In the world practice, electrical energy storage systems are used not only for supporting RES, but also, for frequency and voltage regulation, electric supply reserve etc. However, statistics show that the global production of electricity is provided mainly by burning hydrocarbons [1], and given their low cost, established system of extraction, preparation, transportation, as well as a high-level development of technologies for obtaining electricity from them, these energy sources, remain the main source of electricity. At the moment it is too early to discuss about large-scale application of electrical energy storage systems to increase the efficiency of electricity generation, which is associated with their high cost, however the application in local isolated power systems is a promising direction and it possible to improve the efficiency of traditional power plants.



2. Features of Isolated Power

About 2/3 of the territory of Russia does not have a centralized power supply, (Figure 1). There are thousands of settlements, industrial enterprises, as well as oil and gas production facilities at this territory. To provide power supply for these facilities mainly diesel or gas local power stations are organized. Often, these areas are characterized by poor transport access. Fuel delivery to facilities, especially located in the Far North and the Far East, involve high costs. Moreover, it is necessary to store a large amount of fuel in the winter when there is a transport link with large settlements.



Figure 1. Electrified of the Russian Federation

When designing diesel power plants, the installed power of generator sets is chosen much higher than the maximum load power, which is associated with such a parameter for the units as Load Acceptance. For diesel units this parameter is 50-60% of the rated power, overestimating of power is justified when the load is variable. The utilization factor of the installed power of generator sets is often at the level of 20-25% in this case. The variable load is characteristic for a number of objects: mining, oil and gas, metallurgical, processing plants, etc. To ensure the stable operation of these objects, a large number of generating sets are often selected, which are constantly switched on to be able to provide a load altering by redistributing it between the generators. This operation mode is non-optimal in terms of fuel consumption and the cost of electricity. In addition, this mode intensively reduces the motor resource of the units, which also leads to high operating costs.

The use of gas is for energy supply of such objects a more attractive way of generating electricity in terms of minimizing fuel costs. But unlike diesel fuel, gas is more difficult to transport. A constant source is needed.

It is possible to re-equip part of the object to natural or associated gas, which is due to their small remoteness from natural deposits. In this case, the construction of gas mains from Siberia to the Far East and China («the Power of Siberia») can contribute to the usage of gas for power generation.

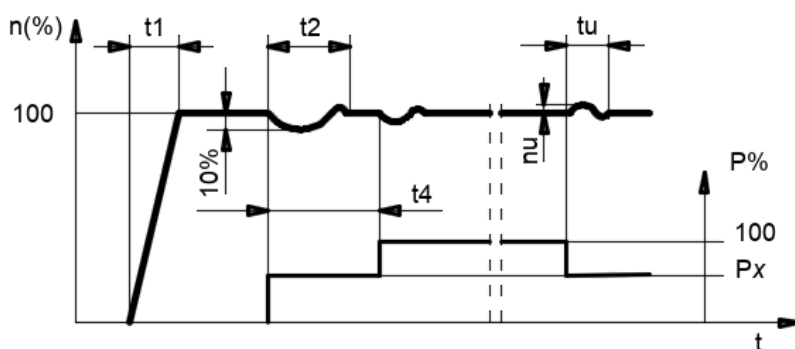


Figure 2. Transient parameters gas generator sets

Gas engine units have a much worse parameter of Load Acceptance, which is associated with greater inertia of the fuel path (Figure 2). Such units are less likely to perceive the outbursts and dumps of the load power, if the values shown in Table 1 (based on the example of a particular manufacturer) are exceeded, they are disconnected by the action of technological protections. The disconnection of one unit entails a chain reaction, leading to the shutdown of the whole power grid. Also, the gas engine units are basically designed in this way, [2] that the normal mode of operation is their loading in the power range from 40 to 100%.

Table 1. Transient parameters of gas generator sets.

Parameters	Symbol	Value
Frequency and voltage transient time during system start-up	t_1	24 s
Transient time when applying the load stage	t_2	10...12 s
Minimum time between load stages	t_4	15 s
Level of the load stage P_x (% of nominal)	P_1	30 %
	P_2	55 %
	P_3	75 %
	P_4	85 %
	P_5	Steps from 5 % to 100 %
Frequency overshoot at load shedding	nu	Less than 6.5 %
Transient time at load shedding	tu	0...13 s

3. Proposed Method

Compensation of power deviations by applying electrical energy storage system, will allow the gas engine power plant to operate in the zone of permissible parameters (Table 1). However, it is necessary to determine the amount of compensation. The complete compensation of the load variation on the one hand improves the operation of the generator sets, allowing to save fuel, and on the other hand leads to an increase in the energy capacity of the electrical energy storage system. Due to the high cost of batteries, this method is economically inefficient. Therefore, there is a need to minimize capacity by using special control algorithms.

We proposed the method which can be used to compensate of the rate of increase in power. The optimal value of optimal speed is set at the control system of EESS which determine the optimum changing of power of the generator set. If the load increases with a higher speed, EESS compensates the difference:

$$\frac{dP_{gen}}{dt} = \frac{d(P(t)_{load} - P(t)_{EESS})}{dt} \quad (1)$$

The proposed mode of operation allows the gas engine generator sets operate in an acceptable mode, while minimizing the energy capacity of electrical energy storage system. In this case, the required energy capacity of the electrical energy storage system can be calculated as:

$$E = \int_{t_1}^{t_2} (P(t)_{load} - P(t)_{gen}) dt \quad (2)$$

The figure 3 illustrates the operation of EESS in the mode of compensation of power increase.

4. Experimental Validation

The proposed method of control was tested in an experimental setup including a 125 kVA diesel generator set, load modules simulating load oscillations, as well as an electrical energy storage system of 100 kVA and 153 kWh. Figures 3-4 show the experimental results of effect of the EESS during the reducing or increasing power load respectively. Figure 5 represents the single line diagram of experiment.

According to graphs the generating set in such modes is loaded smoothly, which confirms the effectiveness of the control by the proposed method. In the course of the experiment, fuel consumption

measurements were also carried out, so the use of EESS allowed to reduce the fuel consumption by 5%.

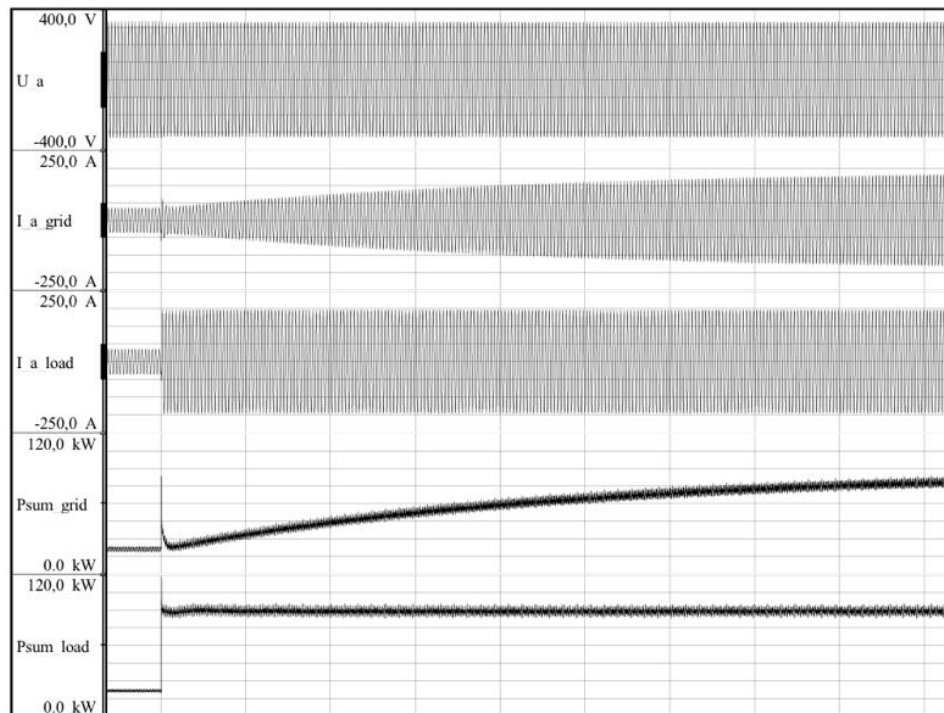


Figure 3. Response to the power draw at the generator and in conjunction with the EESS in the dP/dt compensation mode (from the top: the phase voltage diagram; phase current of the generator; the phase current of the load; the power of the generator; the load power)

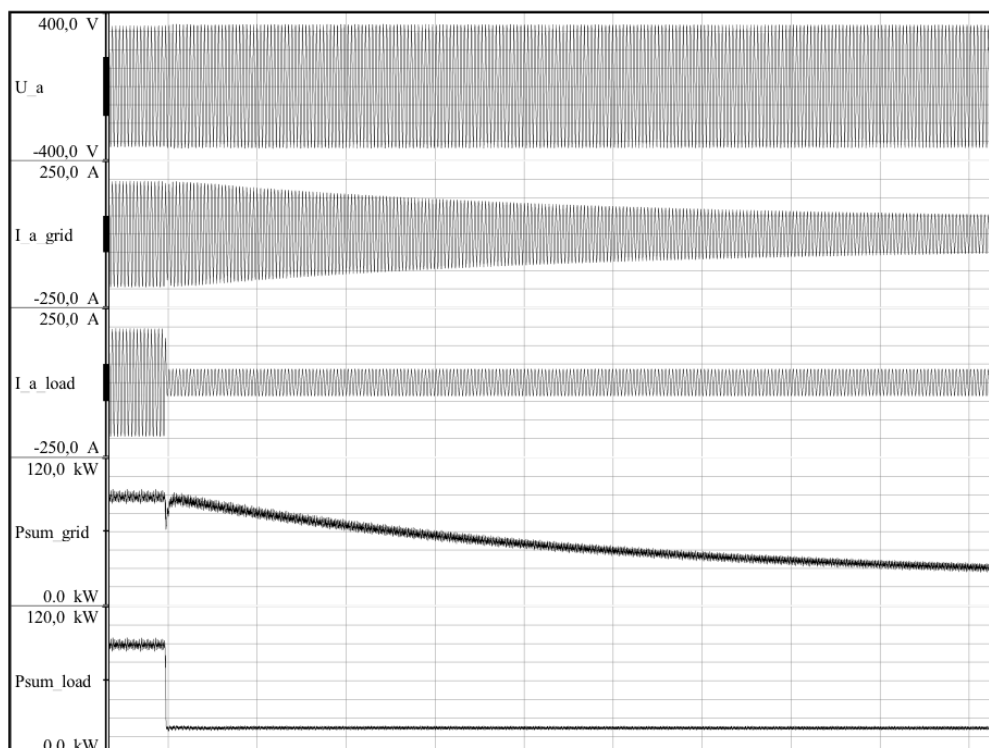


Figure 4. Response to the power reset at the generator and in conjunction with the EESS in the dP/dt compensation mode (from the top: the phase voltage diagram; phase current of the generator; the phase current of the load; the power of the generator; the load power)

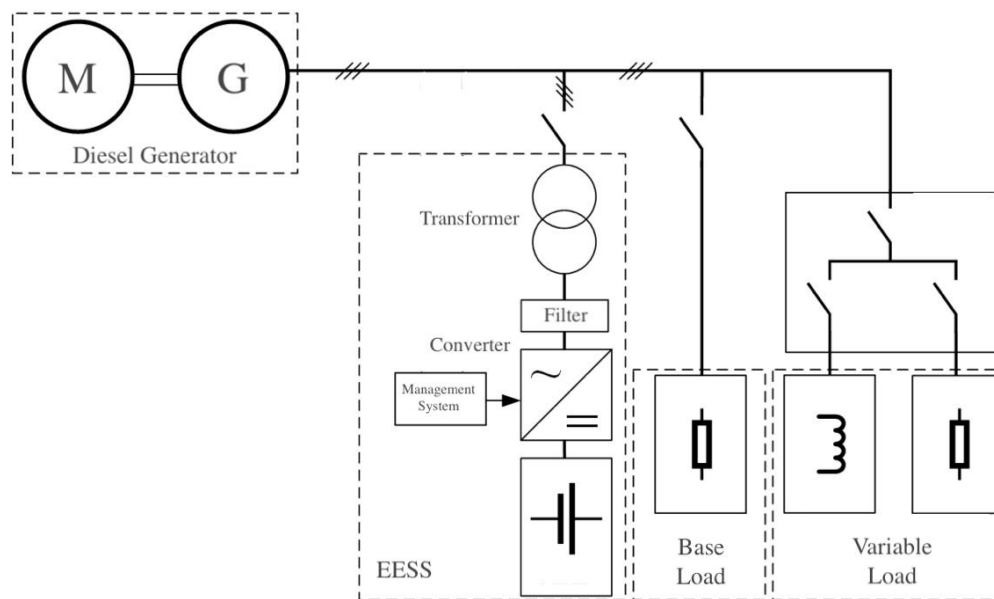


Figure 5. Single line diagrams of experiment

5. Conclusion

Electrical energy storage systems are multifunctional devices, the applications of which is extensive. The method proposed in this paper is effective for ensuring the stable operation of isolated power systems. However, due to the fact that the load oscillations are compensated, as much as is necessary for stable operation of the generators, the energy storage capacity of the electrical energy storage system can be chosen much less. Considering the fact that the cost of storage batteries is at a rather high level, the proposed method will reduce capital costs in the construction of a hybrid isolated power system.

In addition, positive effect is the possibility of replacing diesel generator sets with gas engines at objects where it was previously impossible in terms of operating modes of the power plant. Such solution will allow more than 2 times the fuel transportation costs to be considering, as well as reduce the emissions of toxic substances into the atmosphere, since natural gas is a more environmentally friendly resource compared to diesel fuel.

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